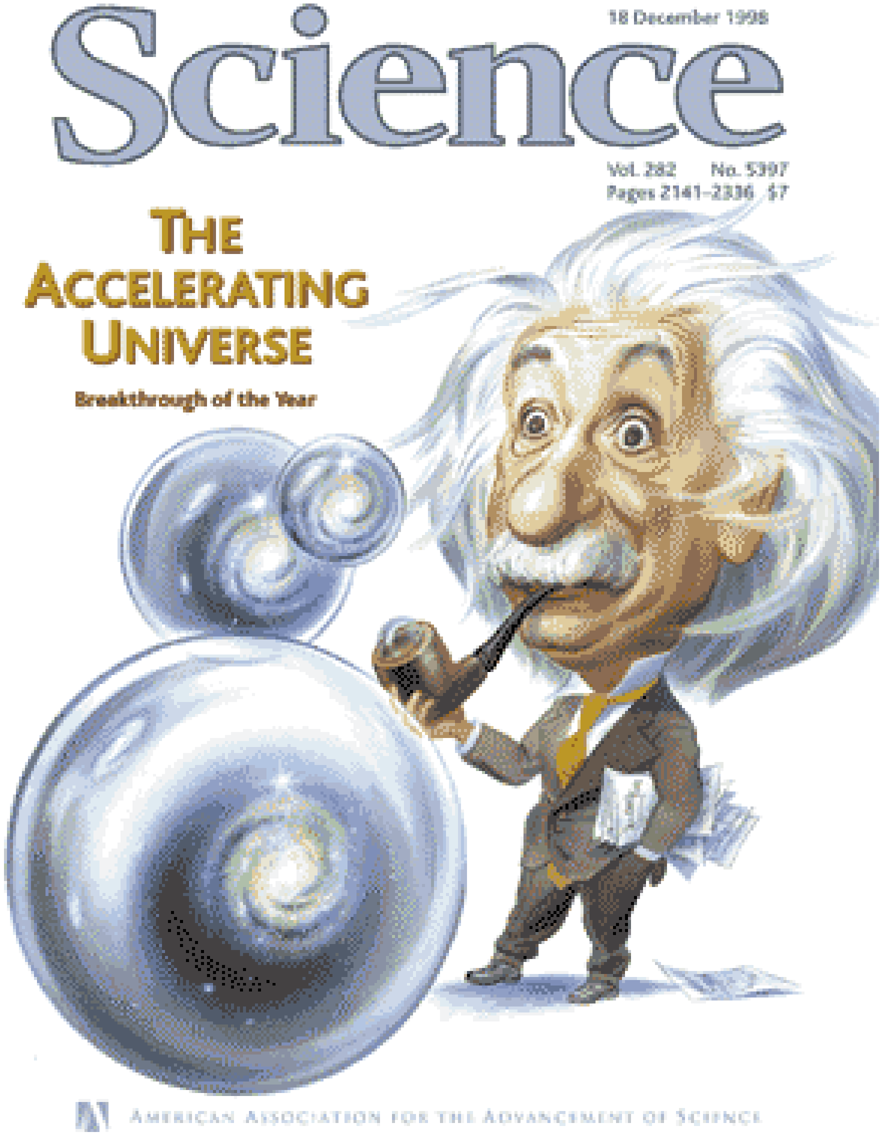
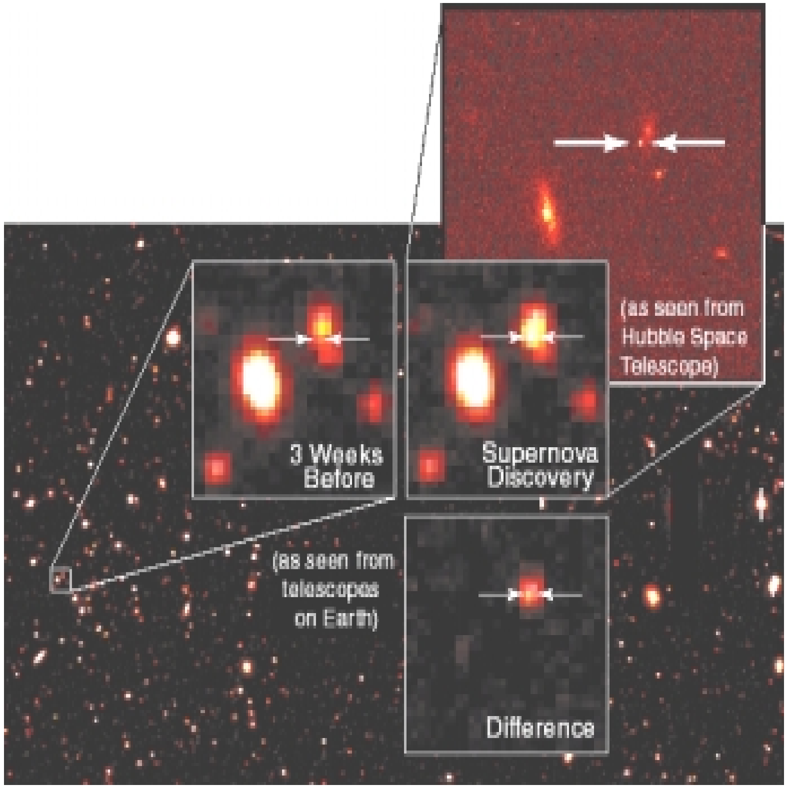
Astrophysics to Understand the Universe
Mass Density, Vacuum Energy Density, and Curvature





Fundamental Questions:

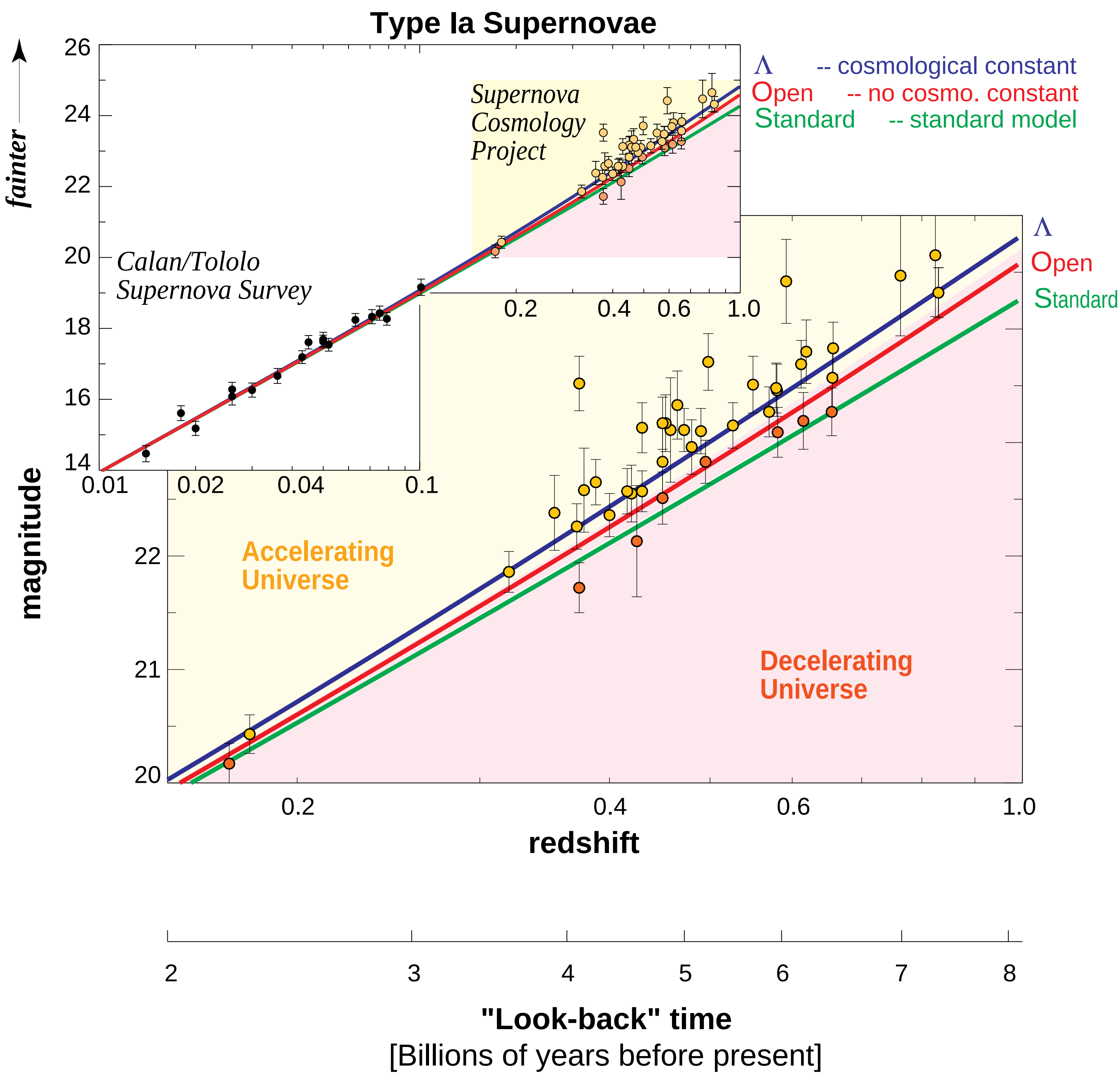
- *Will the universe last forever?*
- *Is the universe infinite?*
- *What is the universe made of?*

An unusual moment in human history:

At the beginning of this century, Einstein developed the conceptual tools to address these questions empirically.

In the past decade or so, technology has advanced to the point that we can now make the measurements that begin to answer these fundamental questions.

Progress is now being made with large scientific programs, including the Supernova Cosmology Project and the Cosmic Microwave Background satellites: MAP, and PLANCK.


Type Ia Supernovae
fainter
magnitude
Calan/Tololo Supernova Survey
Supernova Cosmology Project
Λ -- cosmological constant
Open -- no cosmo. constant
Standard -- standard model
Λ
Open
Standard
Accelerating Universe
Decelerating Universe
26
24
22
20
18
16
14
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1.0
22
21
20
redshift
2
3
4
5
6
7
8
"Look-back" time
[Billions of years before present]

The implications of an accelerating universe:

1. The expansion is not slowing to a halt and then collapsing (i.e., the universe is *not* "coming to an end"). In the simplest models, it will expand forever.

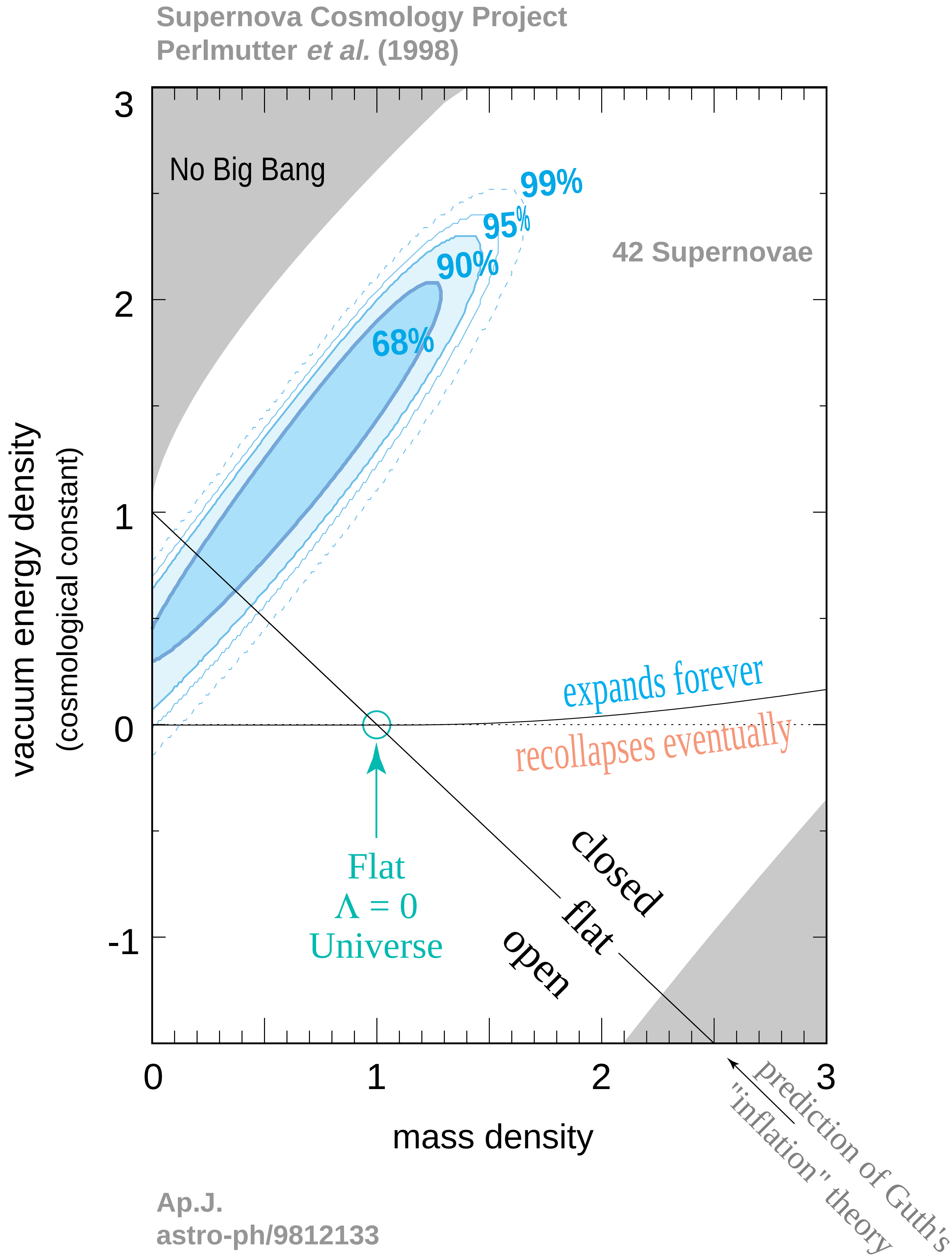
2. There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

   This new accelerating energy ("dark energy") has a larger energy density than the mass density of the universe (or else the universe's expansion wouldn't be accelerating).

What we don't know is:

1. How much of mass density and dark energy density is there? I.e., how much dark matter and dark energy do we need to look for?
   The answer to this question determines the "curvature" of the universe, and can tell us about the extent of the universe: infinite or finite.

2. What is the "dark energy"? Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.



Supernova Cosmology Project
Perlmutter *et al.* (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
expands forever
recollapses eventually
closed
flat
open
Flat
Λ = 0
Universe
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3
prediction of Guth's
"inflation" theory
Ap.J.
astro-ph/9812133

Dark Energy Observer

SNAP: Supernova / Acceleration Probe

BERKELEY LAB

SNAP Dark Energy Observer

supernova / acceleration probe

satellite overview

- **1.8m aperture telescope**

  Can reach very distant SNe.

- **1 square degree mosaic camera, 1 billion pixels**

  Efficiently studies large numbers of SNe.

- **3-channel spectroscopy, 0.3um -- 1.8um**

  Detailed analysis of each SN.

MIDEX+ class satellite:

Dedicated instrument.

Designed to repeatedly observe an area of sky.

Essentially no moving parts.

4-year construction cycle.
3-year operation for experiment
(lifetime open-ended).

SNAP Dark Energy Observer

supernova acceleration probe
satellite baseline specifications

Aperture	1.8m
F.O.V.	1 square degree
Launch Vehicle	Delta II 7920

Image array	36k x 36k mosaic CCD
Architecture	2k x 4k 10-micron pixels
Plate Scale	10 micron/0.10 arc-sec

Image Array Bands	B,V,R,I,Z
Q.E.	65% @ 1000nm (LBNL CCD)
	92% @ 900nm
	>85% @ 400nm-800nm
Read Noise	<2-4 e-
Dark Current	0.08 e-/min/pixel
Image Array Temp.	150K

Spectroscopy	3-channel pick-off:
	325-600nm "Blue" CCD
	+ 600-1050nm "Red" LBL CCD
	+ 1050-1800nm IR (HgCdTe)
Thermal Cooling	passive

Data Downlink	320 Mbps
Data Storage	256 Gbits solid state

Pointing Stability	<0.1 arc-sec
Image Stabilization	2-axis fast steering mirror
Satellite Mass	<1500kg
Power Consumption	<800W

SNAP*SAT*

supernova acceleration probe

one-year baseline data package

Full sample of 2000 SNe between z = 0.3 and 1.7

Discovery within ~2 days of explosion (i.e. ~2 weeks before max).
Most dense coverage between z = 0.3 and 1.0

- Spectra at max for all SNe. (0.3 -- 1.8um)
- Lightcurve points at least 1/week (restframe)
  from -15 to +60 days (restframe)

Discover *every* SN in the field

Nearly continuous monitoring of
~2 sq. deg. to m_{AB} (@1um) $\approx$ 28.5+
~10 sq. deg. to m_{AB} (@1um) $\approx$ 25+
~100 sq. deg. to m_{AB} (@1um) $\approx$ 24+

Satellite follows additional 200 SNe at z < 0.15

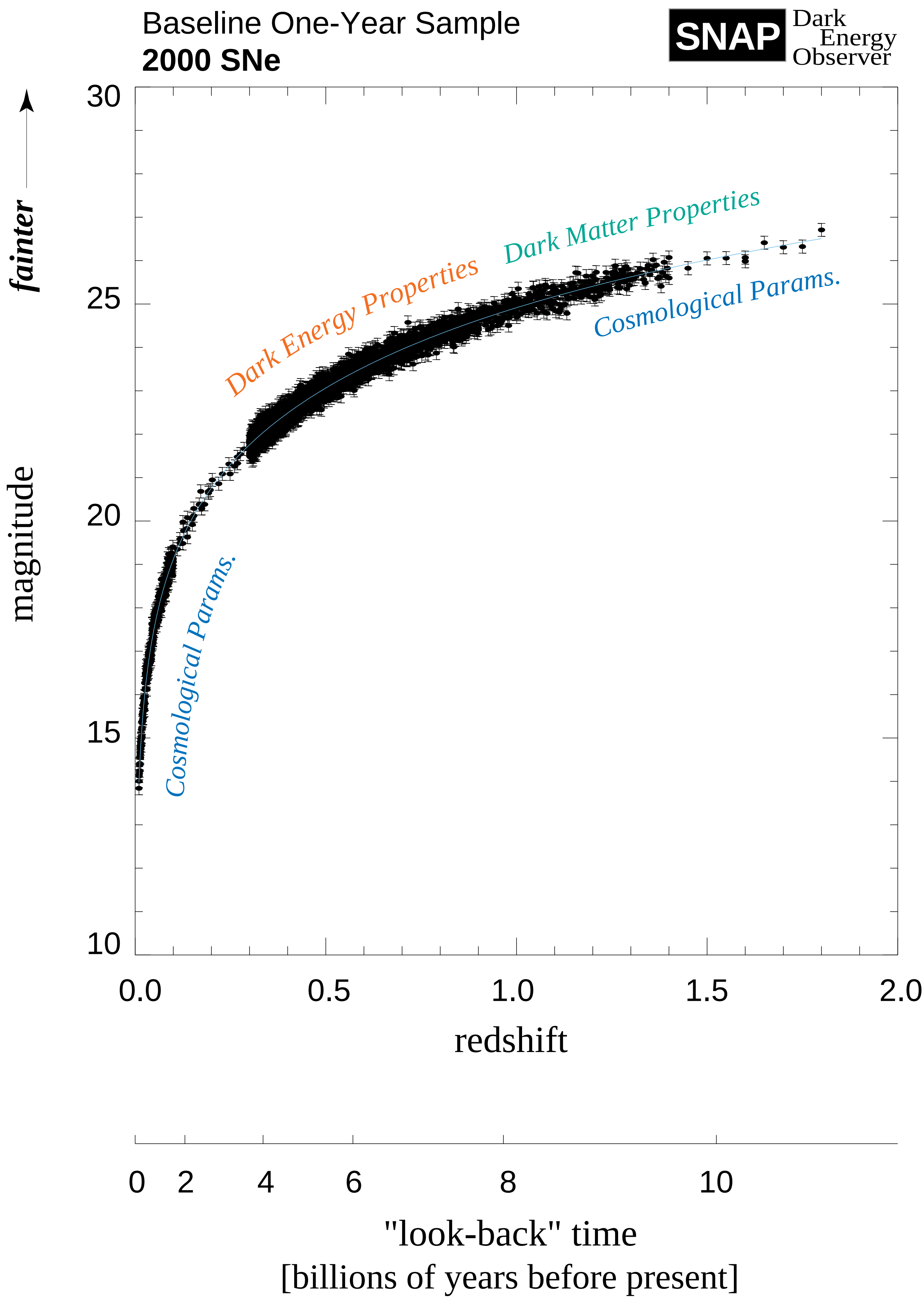
Discovery from ground, follow-up from space to ensure matching spectroscopy/photometry across redshifts.

Subsample of 200 SNe from the full sample

Selected to span
- lightcurve timescales
- galaxy environments
  (morphology, galactocentric radius)
- redshifts

- Spectra at least 2/week (restframe) first month
  1/week (restframe) later

- Synthetic "filter-tuned" photometry from spectra
  for perfect K-corrections



Baseline One-Year Sample
2000 SNe
SNAP
Dark Energy Observer
fainter
magnitude
30
25
20
15
10
0.0
0.5
1.0
1.5
2.0
redshift
Dark Energy Properties
Dark Matter Properties
Cosmological Params.
Cosmological Params.
0
2
4
6
8
10
"look-back" time
[billions of years before present]

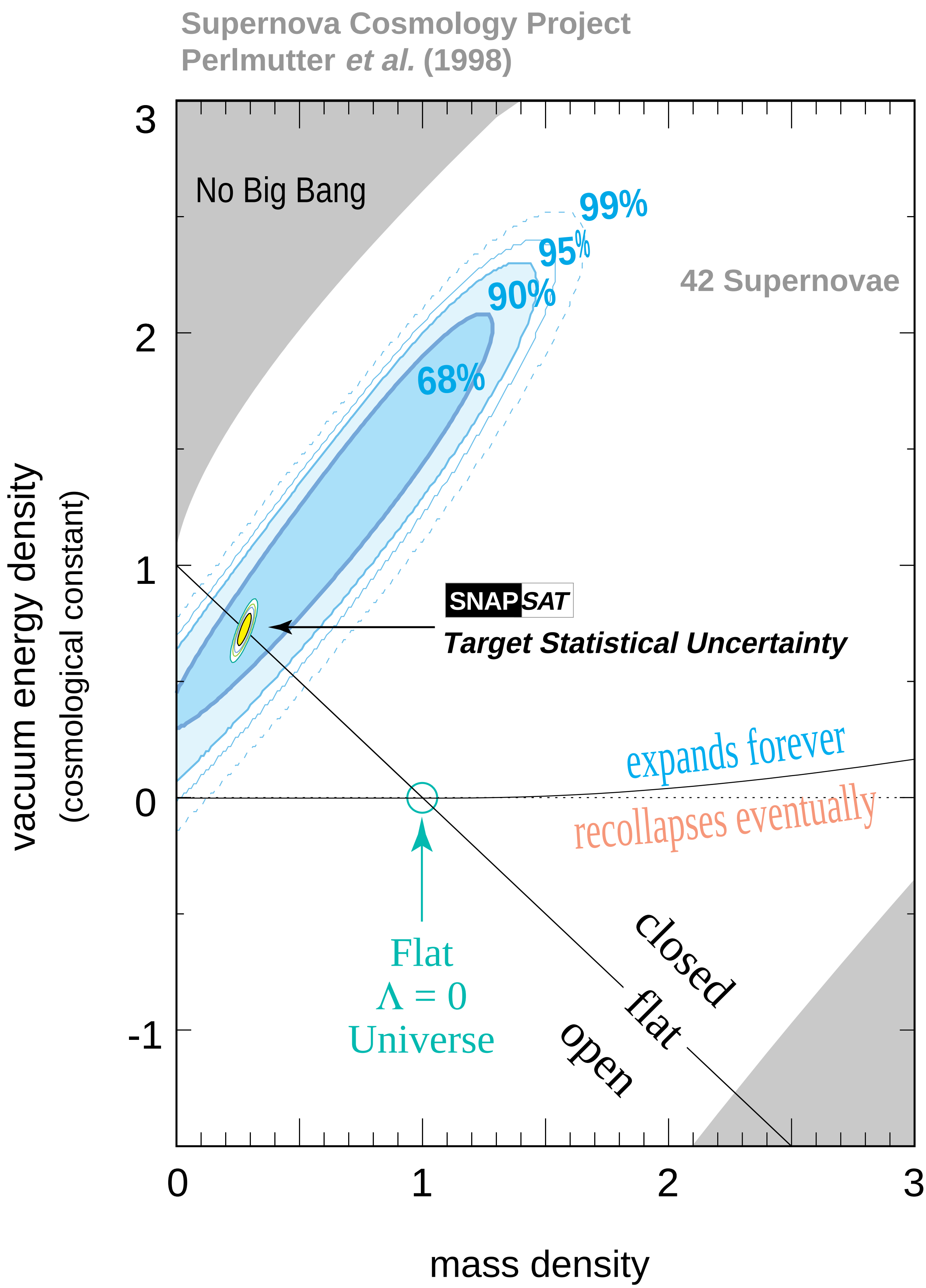
SNAP *SAT*

supernova acceleration probe

baseline science goals

Target Parameter	*Constraint*	*Target Statistical Uncertainty*
Determine mass density, vacuum energy density, and curvature		
mass/vacuum energy Ω_M, Ω_Λ	in flat universe Ω_k=0	0.01
curvature Ω_k	(indep. of CMB)	0.05
mass density Ω_M	unconstrained Ω_k	0.02
vacuum energy Ω_Λ	"	0.05
Properties of Dark Energy		
Eq. of State w vs Ω_M	in flat universe	
Eq. of State w	with $\Omega_M \approx 0.3$	0.05
Study time-varying $w(t)$ by studying $d_L(z)$ with $\Delta z \approx 0.03$ bins.		

A definitive supernova cosmology measurement.



Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
SNAPSAT
Target Statistical Uncertainty
expands forever
recollapses eventually
closed
flat
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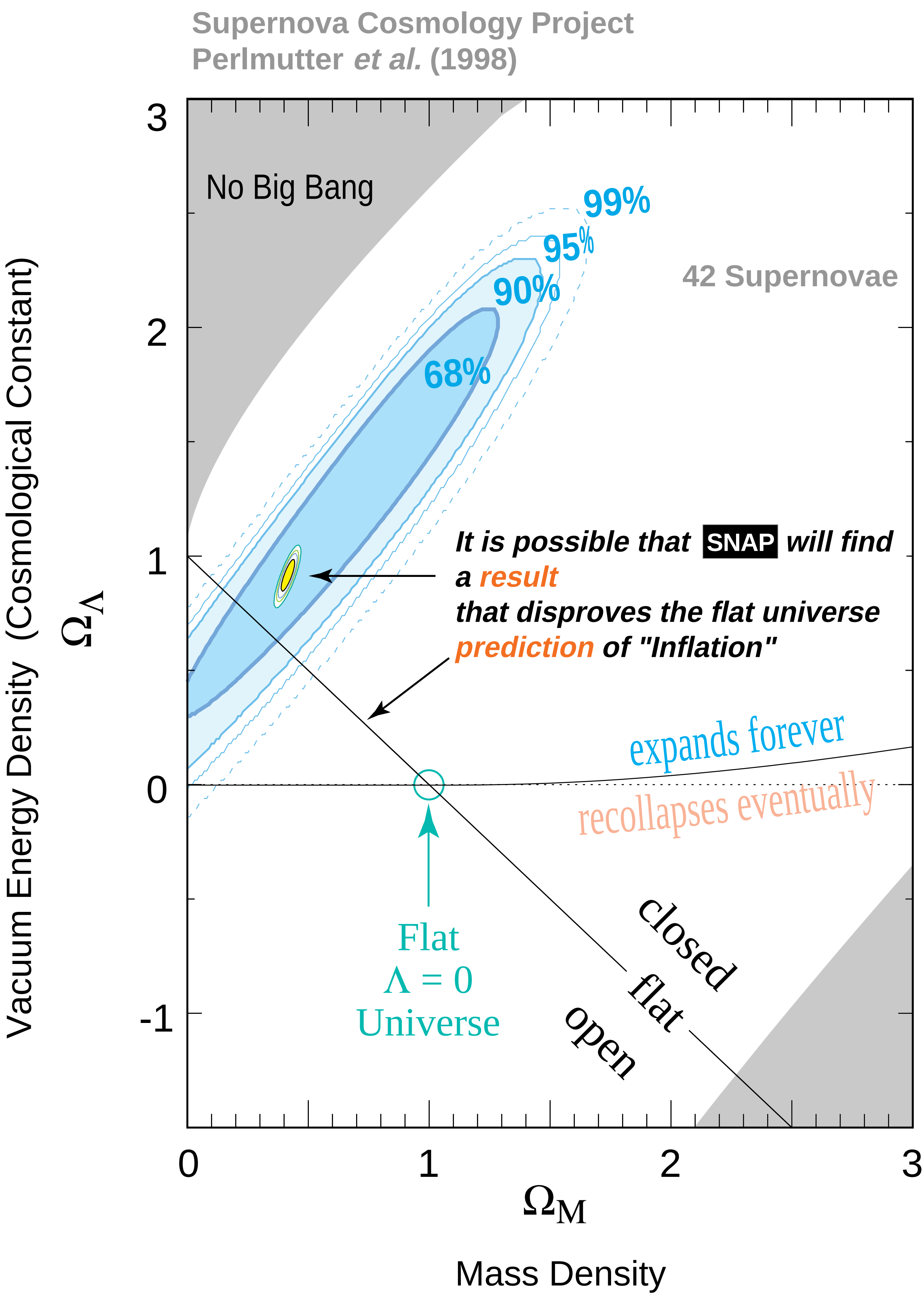
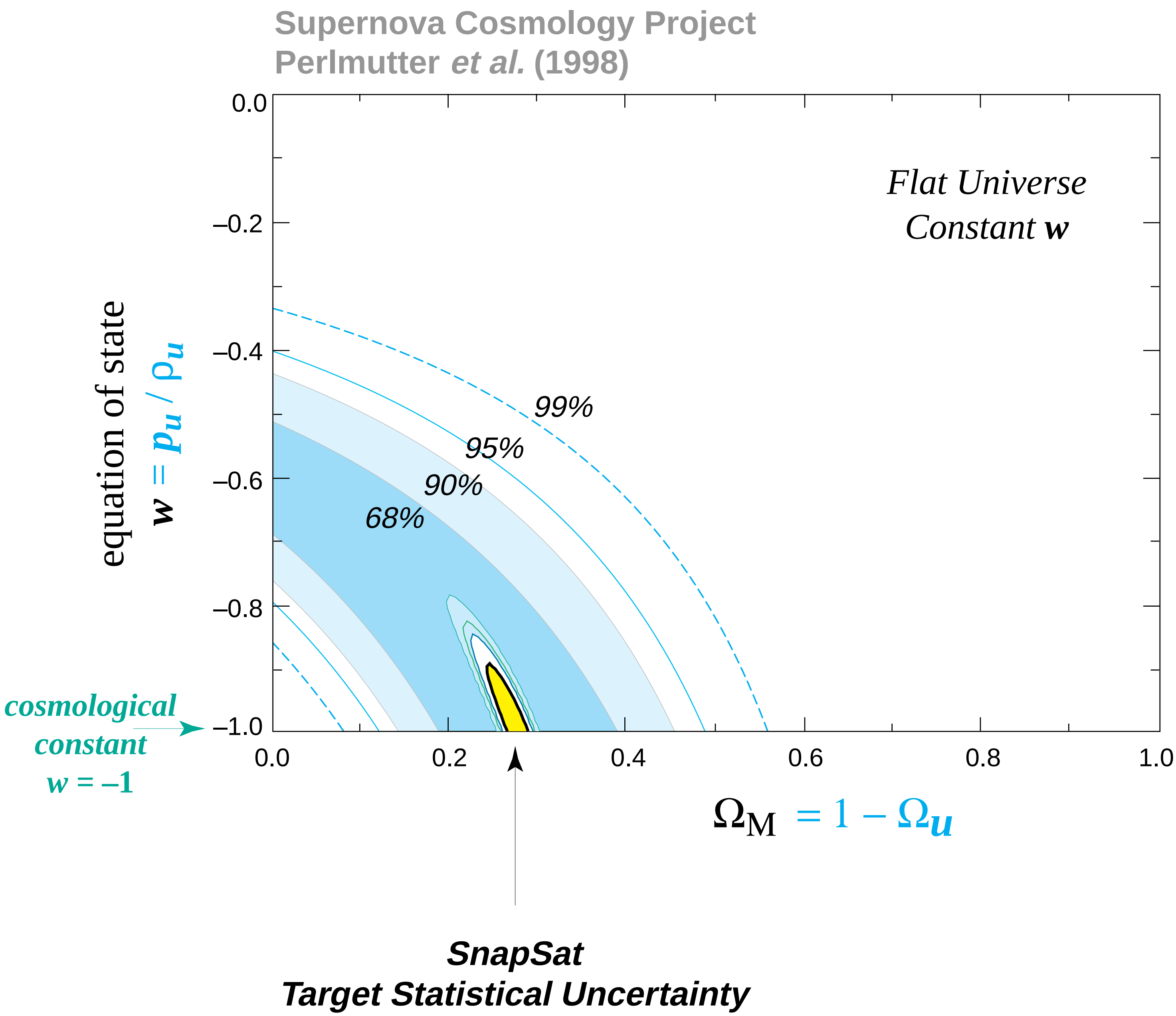
Flat
Λ = 0
Universe
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
It is possible that SNAP will find
a result
that disproves the flat universe
prediction of "Inflation"
expands forever
recollapses eventually
closed
flat
open
Flat
Λ = 0
Universe
3
2
1
0
-1
0
1
2
3
Ω_Λ
Vacuum Energy Density (Cosmological Constant)
Ω_M
Mass Density

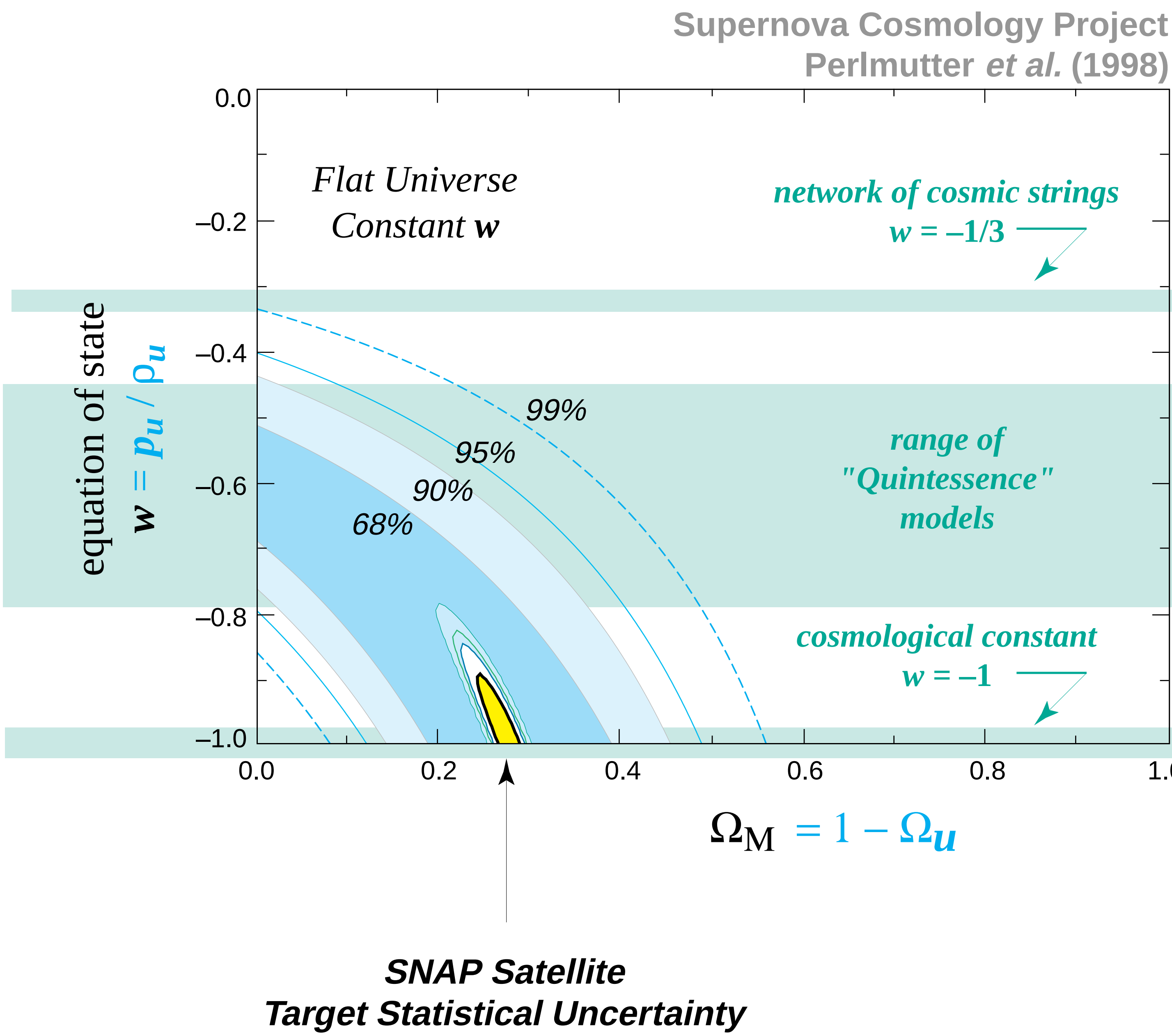
Dark Energy

Unknown Component, Ω_u, of Energy Density



Dark Energy

Unknown Component, Ω_u, of Energy Density



SNAP ***SAT***

supernova acceleration probe

controls for systematics

Dust and Extinction

Determine individual extinctions laws for a given supernova, using range of color measurements into near IR.

Determine gray dust contribution (if any), tracking $d_L(z)$ to high z.

SN Progenitor Age and Metallicity Effects

Studies of lightcurve-timescale (and spectral) luminosity indicators with significant sample of SNe in all host galaxy environments.

Measurement Systematics

Observe all SNe at all redshifts with single, calibrated, stabile photometry/spectroscopy system.

(Avoid multiple instruments with different atmospheric/moon conditions.)

SNAP *SAT*

supernova acceleration probe

complementary science

Cosmological Parameters...

Type II supernova expanding photosphere, Ω_M, Ω_Λ at $z \approx 0.5$
Strong lensing statistics. Ω_Λ
Weak lensing
Galaxy clustering, $P(k)$
$z > 1$ clusters and associated lensing
. . .

...and Beyond

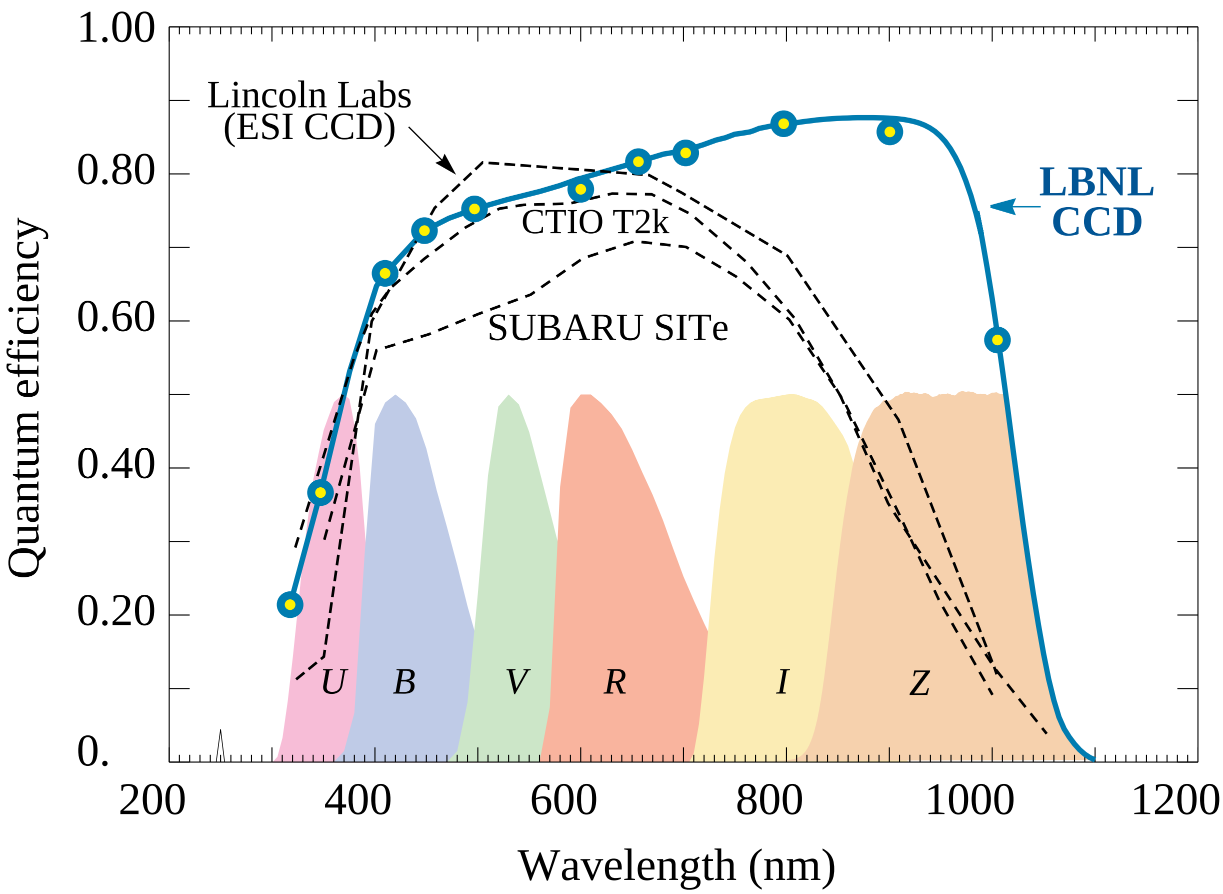
GRB optical counterparts: rates, lightcurves, and spectra
MACHO optical counterparts by proper motion
Galaxy populations and morphology to co-added $m \approx 32$
Target selection for NGST
Kuiper belt objects
Supernova rates, star formation rates
Supernova phenomenology studies
Low surface brightness galaxies, luminosity function
. . .

Roadmap for the
Supernova Cosmology
Project

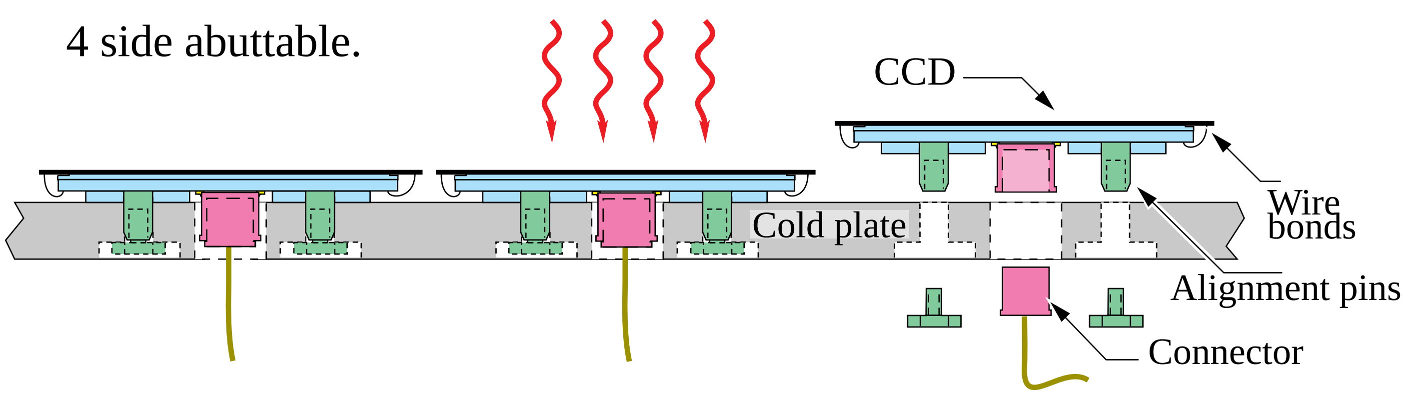
	Nearby SN Factory	Subaru +Keck+HST Key Project	NGST Key Project	SNAPSat
SNe / Year				
@ $z < 0.06$	100	.	.	100
@ $z \sim 0.5$	.	12	.	1000
@ $z > 1$	.	4	20	900
Duration	2 yrs	3 yrs	3 yrs	2 yrs
Calibrated Candle	✓	✓	✓	✓
Reddening Measure	✓	✓	✓	✓
Gray Dust Measure	✓	✓	✓	✓
Metallicity Measure	.	.	✓	✓
Evolution Checks	✓	.	.	✓
Standardized Datasets	.	.	.	✓

LBNL CCD Technology

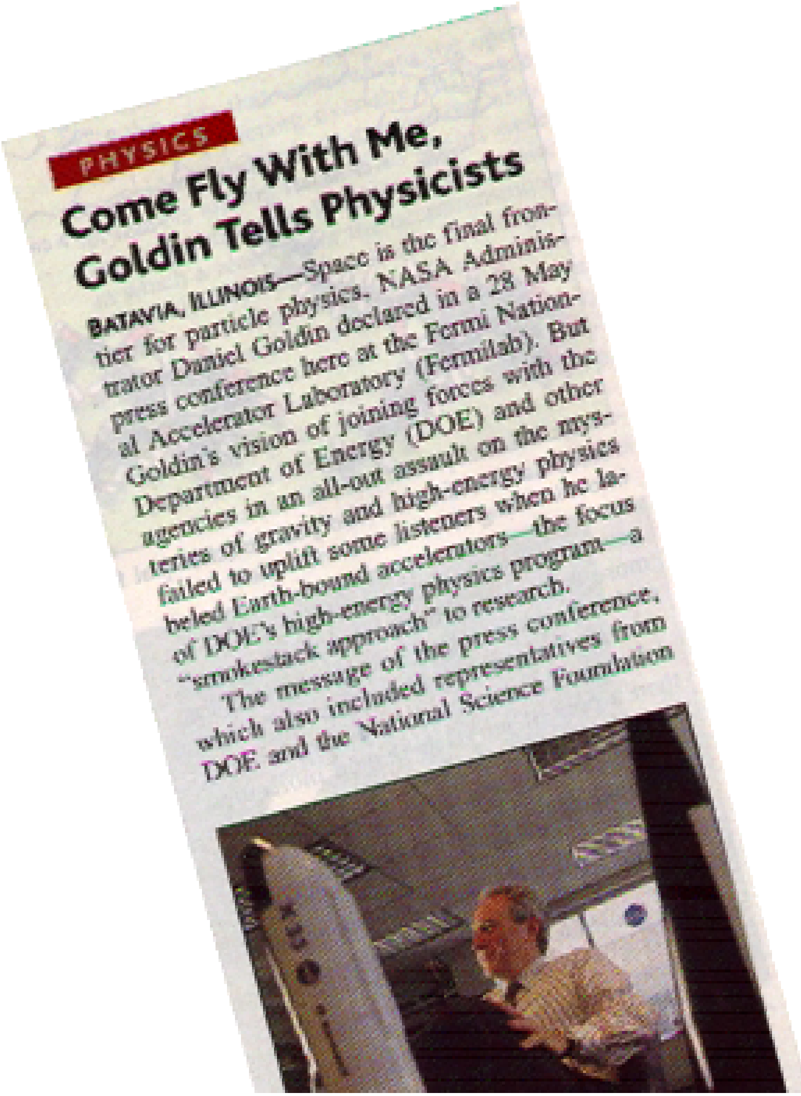
High quantum efficiency from near UV to near IR
No thinning, no fringing.
High yield.
Radiation hard.



4 side abuttable.



NASA Interest in New Astrophysics Probes



PHYSICS

Come Fly With Me, Goldin Tells Physicists

BATAVIA, ILLINOIS—Space is the final frontier for particle physics, NASA Administrator Daniel Goldin declared in a 28 May press conference here at the Fermi National Accelerator Laboratory (Fermilab). But Goldin's vision of joining forces with the Department of Energy (DOE) and other agencies in an all-out assault on the mysteries of gravity and high-energy physics failed to uplift some listeners when he labeled Earth-bound accelerators—the focus of DOE's high-energy physics program—a "smokestack approach" to research.

The message of the press conference, which also included representatives from DOE and the National Science Foundation

"... in the quest to quantify the expansion of the Universe, astronomers may have uncovered a new physical phenomenon -- a kind of vacuum energy they call the Cosmological Constant. This exciting discovery may have given astronomers and physicists an unexpected clue about fundamental physics."

Daniel S. Goldin, May 28, 1999
Fermilab Inner Space-Outer Space Conference